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Investigating the effect of area type and traffic conditions on distracted driving performance

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Abstract

Although driver distraction can be considered as part of everyday driving it constitutes a basic contributory factor for increased risk for road accidents internationally. Within this content, cell-phone use and conversation with passenger are two critical in-vehicle distraction conditions with respect to driver behavior and safety. The objective of this research is the investigation of the effect of area and traffic conditions on driving performance of drivers while talking on the mobile phone or conversing with the passenger. For this purpose, a large driving simulator experiment is carried out, in which 95 drivers from all different age groups (young, middle aged and older) were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in rural and urban road environment, in low and high traffic. In the next step, an appropriate modelling methodology has been developed, including first descriptive analysis in order to explore the large database. Then generalized linear models as well as generalized linear mixed models regarding average speed and reaction time were implemented in order to estimate the effect of the examined distraction sources as well as area and traffic characteristics on driving behaviour and road safety. Results indicate that female drivers, especially in rural areas, were found to have the worst reaction times, while being distracted (either conversing with a passenger or talking on the cell phone). This is probably explained by the fact that in urban area, the complex road environment alerts the drivers in order to self-regulate their driving to compensate for any decrease in attention to the driving task. Furthermore, regarding average speed, it is observed that in rural areas drivers reduce the speed while distracted either by talking on the mobile phone (older drivers) or by conversing with the passenger (young and middle aged drivers), especially at high traffic volume while in urban areas suggesting a driver's compensatory behaviour. The next steps of the present research could focus on the investigation of the impact of mobile phone use, not only when the drivers talk on mobile phone using a hand-held device, but also when they use a hands-free device, a Bluetooth, or when they type messages.

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1. Background and Objectives

Driver distraction is estimated to be an important cause of vehicle accidents. Although driver distraction can be considered as part of everyday driving, the penetration of various new technologies inside the vehicle, and the expected increase of use of such appliances in the next years, makes the investigation of their influence on the behaviour of drivers and on road safety very essential. Driver distraction is generally defined as "a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task or event not related to driving, which reduces the driver's awareness, decision making ability and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes" (Regan et al., 2008).

More specifically, driver distraction involves a secondary task, distracting driver attention from the primary driving task (Donmez et al., 2006; Sheridan, 2004) and may include four different types: physical distraction, visual distraction, auditory distraction and cognitive distraction. A distracting activity involves one, or more of these. The act of operating a hand-held cell phone for example, may involve all four types of distraction (Breen, 2009)

- Physical distraction when the driver has to use one or both hands to manipulate the telephone to dial a number, answer or end a call instead of concentrating on the physical tasks required by driving (Young et al., 2003).
- Visual distraction is caused by the amount of time that the drivers' eyes are on the cell phone and off the road or, while talking over the telephone, looking at the road but failing to see. The use of cell phones that display visual information (e.g. reading SMS) while driving will further distract drivers' visual attention away from the road (Dragutinovits and Twisk, 2005).
- Auditory distraction can occur when the driver is startled by the initial ringing of the telephone or by the conversation itself.
- Cognitive distraction involves lapses in attention and judgment. It occurs when two mental tasks are performed at the same time. Conversation competes with the demands of driving. Listening, alone, can reduce activity in the part of the brain associated with driving by more than a third (Ma et al., 2008). The extent of the negative effects of cell phone use while driving depends on the complexity of both cell phone conversations and of driving situation. The more difficult and complex the conversation, the stronger its effects on driving performance. The more difficult the driving situation, the more impact the telephone conversation can be expected to make (SWOW, 2008).

Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). The in-vehicle sources of distraction include the use of mobile phone (either for conversing or for texting), conversation with passengers, smoking, eating or drinking, listening to music and in-vehicle assistance systems (e.g. navigation systems) (Johnson et al., 2004; Stutts et al. 2005; Neyens & Boyle 2008), and their effects are largely examined by means of simulator experiments (Horberry et al. 2006; Bellinger et al. 2008). For the purpose of this research, an extensive literature review was carried out, presenting driving simulator studies on driver distraction, with emphasis on the effects of mobile phone use and conversation with passengers.

Several studies attempt to compare the effect of mobile phone use and passenger conversation through driving simulator experiments. In Laberge et al. (2004), eighty participants were randomly assigned to one of three conditions: driving alone, driving with a passenger, and driving with a cellular phone and results indicate that lane and speed maintenance were influenced by increased driving demands. Furthermore, response times to a pedestrian incursion increased when the driver was driving and talking compared with those detected when the driver was not talking at all.

Drews et al. (2008), examined how conversing with passengers in a vehicle differs from conversing on a mobile phone while driving by comparing how well drivers were able to deal with the demands of driving when conversing on a mobile phone, conversing with a passenger, and when driving without any distraction. The results show that the number of driving errors was highest in the mobile phone condition; in passenger conversations more references were made to traffic, and the production rate of the driver and the complexity of speech of both interlocutors dropped in response to an increase in the demand of the traffic.

Regarding the effect of area type, Burns et.al (2008) found that 2.8% of drivers were using mobile phones at any given moment while driving in rural areas, but this figure was much higher (5.9%) in urban areas. Furthermore, in an exhaustive literature review on driving simulator experiments on driver distraction, Papantoniou et.al (2013) found that regarding the simulated road environment that most driving scenarios concern rural road environment, while less than 30% concern motorways. The relatively smaller proportions of urban environments may be partly attributed to the researcher’s effort to minimize simulator sickness, which is known to be more intense in more complex settings. However, in-vehicle distraction may be equally or more important in urban areas, where the driver is by default exposed to several other ‘distractors’ (e.g. traffic signs, other vehicles or pedestrians, advertising, architecture and commercial activities etc.

Within this content, cell-phone use and conversation with passenger are two critical in-vehicle distraction conditions with respect to driver behavior and safety. The objective of this research is the investigation of the effect of area and traffic conditions on driving performance of drivers while talking on the mobile phone or conversing with the passenger. For this purpose, a large driving simulator experiment is carried out, in which 95 drivers from all different age groups (young, middle aged and older) were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in rural and urban road environment, in low and high traffic.

The paper is structured as follows. Regarding the methodology and data, an overview of the experiment is provided followed by the driving simulator experiment procedure and the sample characteristics. Then, the statistical analysis theoretical background is provided for both types of analysis. Finally, the results are presented and discussed and some concluding remarks are provided.

2. Methodology and data

2.1. Overview of the experiment

Within this framework, a driving simulator experiment was carried out, in which 95 participants were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in different road (urban/rural) and traffic conditions (high/low). Each participant aimed to complete 12 different driving trials, while in each trial, 2 unexpected incidents were scheduled to occur at fixed points along the drive. Then, participants were asked to fill in two questionnaires regarding their driving behaviour, as well as self-assessment and memory tests. The above stages were designed on the basis of parameters and criteria shown to be important in the literature, as well as design principles that were appropriate for the research assumptions and objectives of the present research

The driving simulator experiment took place at the Department of Transportation Planning and Engineering of the National Technical University of Athens, where the FOERST Driving Simulator is located. The NTUA driving simulator is a motion base quarter-cab and consists of 3 LCD wide screens 40'' (full HD: 1920x1080 pixels), driving position and support motion base. The dimensions at a full development are 230x180 cm, while the base width is 78 cm and the total field of view is 170 degrees. Research evidence from on-road testing supports the validity properties of the driving simulator that was applied in the current study (Nikas, 2014).

2.2. Driving at the simulator

The driving simulator experiment begins with a practice drive (5-10 minutes), until the participant fully familiarizes with the simulation environment. Afterwards, the participant drives the two sessions (~20 minutes each). Each session corresponds to a different road environment:

- A rural route that is 2.1 km long, single carriageway and the lane width is 3m, with zero gradient and mild horizontal curves.
- An urban route that is 1,7 km long, at its bigger part dual carriageway, separated by guardrails, and the lane width is 3.5 m. Moreover, narrow sidewalks, commercial uses and parking are available at the roadsides.

Within each road / area type, two traffic scenarios and three distraction conditions are examined in a full factorial within-subject design. The distraction conditions examined concern undistracted driving, driving while conversing with a passenger and driving while conversing on a mobile phone.

The traffic scenarios are:

- QL: Moderate traffic conditions – with ambient vehicles' arrivals drawn from a Gamma distribution with mean m=12 sec, and variance σ^2=6 sec, corresponding to an average traffic volume Q=300 vehicles/hour.
- QH: High traffic conditions – with ambient vehicles' arrivals drawn from a Gamma distribution with mean m=6 sec, and variance σ^2=3 sec, corresponding to an average traffic volume of Q=600 vehicles/hour.

Consequently, in total, each session (urban or rural) includes six trials, i.e. six drives of the simulated route. During each trial of the experiment, 2 unexpected incidents are scheduled to occur at fixed points along the drive (but not at the exact same point in all trials, in order to minimize learning effects). More specifically, incidents in rural area concern the sudden appearance of an animal (deer or donkey) on the roadway, and incidents in urban areas concern the sudden appearance of an adult pedestrian or of a child chasing a ball on the roadway (Figure 1). The experiment is counterbalanced concerning the number and the order of the trials, on the basis of several combinations of the parameters of interest

Fig. 1. Unexpected incident - donkey crossing the lane / child with ball crossing the road.

2.3. Sample characteristics

In Table 1 the distribution of participants per age and gender is presented. It is shown that almost half of the participants are males (47) and half females (48) indicating that the there is a total balance in the sample regarding gender and age groups.

Table 1. Distribution of participants per age group and gender.

Age group	Female		Male		Total	
18-34	9	19%	19	40%	28	29%
35-55	19	40%	12	26%	31	33%
55+	20	42%	16	34%	36	38%
Total	48	100%	47	100%	95	100%

In Figure 2 the distribution of driving trials is presented per area type and order of trials. It is shown that 95 participants started the experiment by driving in the first sessions in rural area. However, only 48 drivers managed to complete all 6 driving trials. The respective number is 41 regarding the 6 trials in urban area.

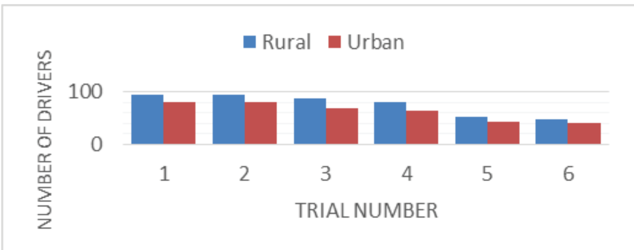

Fig. 2. Distribution of number of driving trials.

This is explained by the fact that a significant number of participants came up with simulator sickness symptoms during the experiment and did not manage to complete all the trials. In addition, the complex driving simulator environment in urban area enhanced these symptoms resulting in fewer number of participants that drove all urban driving scenarios.

2.4. Analysis background

The large dataset exploited in the present research makes the descriptive analysis of a large number of variables essential. Within this framework, box plots (also known as a box-and-whisker charts) is a convenient way to show groups of numerical data, such as minimum and maximum values, upper and lower quartiles, median values, outlying and extreme values. More specifically regarding boxplots

- The line in the middle of the boxes is the median
- The bottom of the box indicates the 25th percentile. Twenty-five percent of cases have values below the 25th percentile. The top of the box represents the 75th percentile. Twenty-five percent of cases have values above the 75th percentile. This means that 50% of the cases lie within the box.

In the next step, linear regression is used to model a linear relationship between a continuous dependent variable and one or more independent variables. Furthermore, the generalized linear model (GLM) is a flexible generalization of ordinary linear regression that allows for inclusion of dependent variables that have error distribution models other than a normal distribution. The GLM generalizes linear regression by allowing the linear model to be related to the response variable via a link function. It also allows the magnitude of the variance of each measurement to be a function of its predicted value (Washington et al., 2011).

The structure regarding each individual regression analysis is the following. Starting with the description of the model, both the dependent and independent variables are recorded in order to set the target of each analysis. Then, the parameter estimates are summarized along with the standard errors, t- and p-values. Before accepting the results of the model it is important to evaluate their suitability in explaining the data. One way to do this is to visually examine the residuals. If the model is appropriate, the residual errors should be random and normally distributed. In addition, removing one case should not significantly impact the model's suitability. That statistical software R provides four graphical approaches for evaluating the models as follows: The residual errors plotted versus their fitted values, the square root of the standardized residuals as a function of the fitted values, the standard Q-Q plot, and each point's leverage.

Furthermore, as presented in the description of the driving simulator experiment, the data used in this research involve repeated measured observations from each individual drive, as each driver completes six drives in rural and six drives in urban environment. For this reason, in order to deal with the heterogeneity across individuals, generalized linear mixed models are implemented and presented next for each model. Then, the likelihood ratio test is taking place in order to examine the goodness-of-fit for each pair of models. The purpose is to prove that the random effect contributes significantly to the fit of the model and therefore, the fit of the generalized linear mixed models outperforms respective generalized linear models.

3. Results

3.1. Descriptive analysis

In this section the effect of road and traffic environment on specific driving performance variables is graphically presented. More specifically, the figures presented next show the effect of area type and traffic condition on average speed and reaction time of drivers at unexpected incidents for different types of distraction (undistracted driving, conversing with the passenger and talking on the cell phone).

Boxplots in Figure 3 illustrate that average speed is, as expected, lower in urban areas than in rural areas both in high and low traffic. Furthermore, in high traffic the effect of distraction on average speed is less significant. On the other hand, in low traffic conditions in rural areas, talking on the cell phone leads to reductions in average speed in the framework of the compensatory behaviour of the driver.

The right part of figure 3 indicates that both in rural and urban areas in low traffic conditions distracted driving results to increased reaction time. Inside urban area, driver reaction time while conversing with the passenger is clearly higher than talking on the cell phone. This indicates that the often lack of vision on the road of drivers when conversing with the passenger is very dangerous in a complex environment of urban areas.

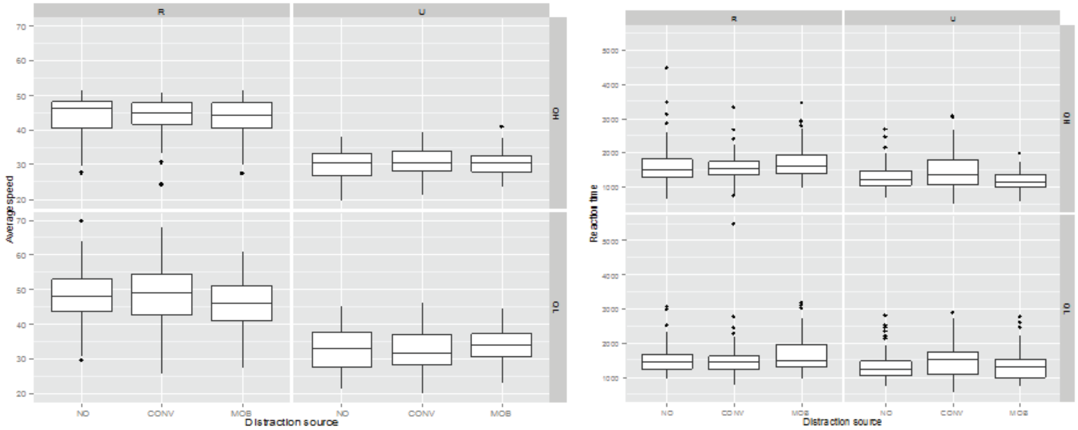

Fig. 3. Average speed and reaction time per distraction factor, area type and traffic condition.

3.2. Regression analysis

The relationship between speed and accidents is widely recognised in the road safety community and as such, speed is a commonly used dependent variable in transportation human factors research including driver distraction research. The first regression model investigates the relationship between the vehicle average speed and several explanatory variables, namely driver characteristics such as age groups and gender, road and traffic characteristics such as area type and traffic condition, as well as the use of cell phone. The model parameter estimates are summarized in Table 2.

Table 2. Parameter estimates of the GLM of average speed.

Variables	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	44,847	0,40	111,04	< 0,000
Distraction - Cell phone	-1,217	0,43	-2,82	0,005
Age group - Older	-6,150	0,41	-14,99	< 0,000
Gender - Male	2,675	0,37	7,25	< 0,000
Area type - Urban	-14,536	0,37	-39,31	< 0,000
Traffic - Low	3,170	0,37	8,64	< 0,000
Summary statistics				
AIC	5.183,80			
Log-restricted-likelihood	-2.584,90			
Degrees of freedom	837			

Following the evaluation of the suitability of the model, the following graphs are provided (Figure 4). In the upper left graph the residuals are randomly distributed around the horizontal line. In the upper right graph there is no obvious trend in the standard deviation of the residuals. In the Q-Q plot, residuals are on the dotted line while the last diagram is a measure of importance in determining the regression results. All graphs indicate the suitability of the model.

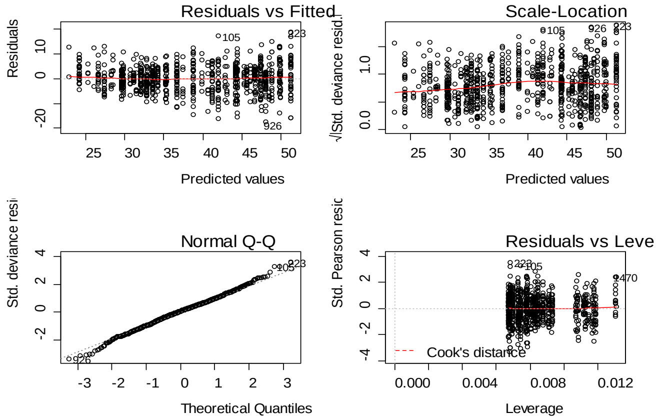

Fig. 4. Average speed GLM graphical approach of residuals.

Since the data involve repeated measured observations from each individual drive, the generalized linear mixed model is implemented and presented in Table 3.

Table 3. Parameter estimates of the GLMM of average speed.

Variables	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	44,847	60,69	60,69	< 0,000
Distraction - Cell phone	-1,217	-6,96	-6,96	< 0,000
Age group - Older	-6,150	-7,32	-7,32	< 0,000
Gender - Male	2,675	2,68	2,68	0,009
Area type - Urban	-14,536	-56,22	-56,22	< 0,000
Traffic - Low	3,170	11,94	11,94	< 0,000
Random effect				
By Person ID (stdev)	4,075	-		
Summary statistics				
AIC	4.809,87			
Log-restricted-likelihood	-2.396,94			

Finally, the likelihood ratio test is taking place in order to examine the goodness-of-fit of the GLMM model. The likelihood ratio test is $LR_{av.speed}$= -375,92 (1 degree of freedom) indicating that the random effect contributes significantly to the fit of the model. Therefore, the fit of the generalised linear mixed model outperforms the respective fit of the generalized linear model.

The final generalised linear mixed model results indicate that several parameters have a statistically significant impact on the average speed of drivers during the driving simulator experiment.

Regarding the distraction sources examined, the use of cell phone while driving results in reduced speeds for all drivers. On the other hand, while conversing with the passenger, drivers do not change significantly the average speed. It can be assumed that the reduction in vehicle speed of drivers using their cell phone results in a road safety benefit, given that lower travel speeds are generally correlated with lower accident risk. However, it is also an indication of the drivers' attempt to counter-balance the increased mental workload resulting from the activity in addition to the physical distraction of the handheld mode

Proceeding to road and traffic characteristics, area type has the highest effect on average speed, as drivers in rural areas drive at the highest speeds, as expected due to the less complex driving environment. In addition, in low traffic conditions drivers of all age groups and both genders are able to reach higher average speed as confirmed from the model results.

Concerning driver characteristics, male drivers reach higher average speed compared to female indicating the aggressive driving of male drivers, which is confirmed in the literature. Finally, regarding the effect of different age groups, older drivers decrease significantly their speed while being distracted indicating that they try to compensate their driving performance as they feel more vulnerable compared to young middle aged ones.

The second regression analysis relates the reaction time of drivers at unexpected incidents to several explanatory variables. Since range of reaction time measures can be examined including number of missed events, number of incorrect responses, reaction time and reaction distance, in the present experiment reaction time is measured at specific unexpected incidents. The explanatory variables include driver characteristics such as age group and gender, road environment characteristics such as area type as well as distraction sources. The model parameter estimates are summarized in Table 4.

Table 4. Parameter estimates of the GLM of reaction time.

Variables	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	1.546,15	36,55	42,31	< 0,000
Distraction - Passenger	66,62	37,23	1,79	0,074
Distraction – Cell phone	85,74	41,98	2,04	0,042
Age group - Older	286,3	36,31	7,90	< 0,000
Gender – Male	-181,90	32,53	-5,59	< 0,000
Area type - Urban	-189,01	32,79	-5,76	< 0,000
Summary statistics				
AIC	12.257,00			
Log-restricted-likelihood	-6.121,50			
Degrees of freedom	810			

Following the evaluation of the suitability of the model, the following graphs are provided (Figure 5). All graphs indicate the suitability of the model.

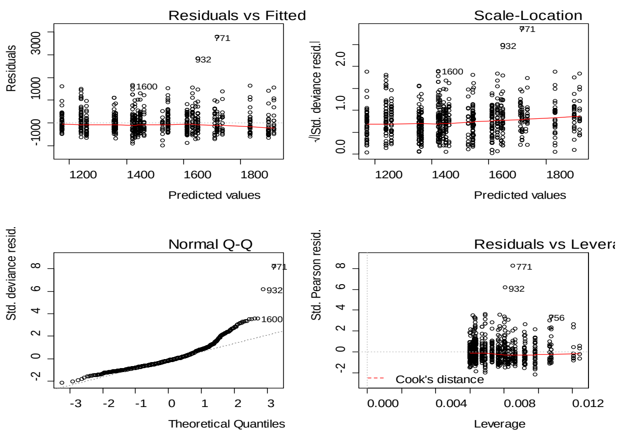

Fig. 5. Reaction time GLM graphical approach of residuals.

Since the data involve repeated measured observations from each individual drive, the generalized linear mixed model is implemented and presented in Table 5.

Table 5. Parameter estimates of the GLMM of reaction time.

Variables	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	1.544,04	43,85	35,22	< 0,000
Distraction - Passenger	69,82	35,67	1,96	0,051
Distraction – Cell phone	91,84	40,85	2,25	0,025
Age group - Older	292,70	48,50	6,09	< 0,000
Gender – Male	-180,36	45,10	-4,00	< 0,000
Area type - Urban	-188,73	31,57	-5,98	< 0,000
Random effect				
By Person ID (stdev)	153,04	-		
Summary statistics				
AIC	12.189,87			
Log-restricted-likelihood	-6.086,52			

The likelihood ratio test with a value of $LR_{Reaction}$= 69,94 (1 degree of freedom) indicates that the random effect contributes significantly to the fit of the model. As a result, the fit of the generalized linear mixed model outperforms the respective fit of the generalized linear model.

Model results indicate that reaction time of the drivers at unexpected incidents exhibited differences between talking on the cell phone, conversing with the passenger and driving without any distraction. It is observed that, while talking on the cell phone or conversing with passenger, drivers of all age groups have higher reaction times compared with undistracted driving. It is also worth noting that young and middle aged drivers experience higher reaction times when conversing with a passenger than talking on the cell phone.

This is explained by the different distraction mechanism that takes place when talking on the cell phone versus when conversing with a passenger while driving. This difference can be attributed to the driver's age. Cell phone use distraction is consisted of prolonged and repeated glances to the cell phone. Therefore, older drivers have difficulty in maintaining cell devices while driving because they are not as practiced and efficient as technological multi-taskers, commonly younger drivers. On the other hand, when conversing with a passenger, drivers' glance is out of the road very often and this has a more pronounced effect on reaction time of young and middle aged drivers.

Regarding the effect of driver characteristics on reaction time, male drivers achieved much better reaction times compared to female drivers indicating that they are probably more concentrated and perform quicker in case of an unexpected incident. Furthermore, older is the age group with the highest reaction time, as expected.

Finally, in urban areas drivers achieve better reaction time than in rural areas probably due to the fact that in urban areas, the complex road environment keeps the drivers alerted, who in turn self-regulate their driving to compensate for their reduced attention to the driving task.

4. Discussion

This paper analyzed the driving performance of drivers of different age groups in order to investigate the effect of area and traffic characteristics on selected driving performance parameters. For this purpose, 95 participants from three different age groups were asked to drive under different types of distraction (no distraction, conversation with passenger, mobile phone use) in urban and rural road environment with low and high traffic volume, while the analysis methodology consists of two statistical analysis namely descriptive statistics and generalised linear regression models.

Results indicate that regarding average speed, area type has the highest effect as drivers in rural area drive in highest speed. Furthermore, the use of a cell phone while driving results in reduced speeds for all drivers. It can be assumed that the reduction in vehicle speeds of drivers using their cell phone results in a road safety benefit, given that lower travel speeds are generally correlated with lower accident risk. However, it is also an indication of the drivers' attempt to counter-balance the increased mental workload resulting from the activity in addition to the physical distraction of the handheld mode. It should be noted that while conversing with the passenger, drivers do not change significantly the average speed neither in different area type nor in different traffic scenarios.

Furthermore, while talking on the cell phone or conversing with passenger, drivers of all age groups achieved higher reaction times compared with undistracted driving. In addition, it is worth noting that young and middle aged drivers indicate higher reaction times when conversing with the passenger than talking on the cell phone explained by the different distraction mechanism between cell phone and conversation with the passenger which is correlated with driver’s age. Furthermore, female drivers, especially in rural areas, were found to have the worst reaction times, while being distracted (either conversing with a passenger or talking on the cell phone). This is probably explained by the fact that in urban area, the complex road environment alerts the drivers in order to self-regulate their driving to compensate for any decrease in attention to the driving task.

In the next steps of the present research it would be important to investigate the impact of mobile phone use, not only when the drivers talk on mobile phone using a hand-held device but also when they use a hands-free device, a Bluetooth, or when they type messages. Furthermore, as compensatory behaviour was found to play a quite critical role on the distracted driving performance of the present experiment, further research should examine what compensatory behaviours drivers use to trade-off and maintain an adequate level of driving and secondary task performance and which of these strategies are most effective in minimising driving degradation

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